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# Investigations of Magnetic Overlayers at the Advanced Photon Source

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**Abstract**

Magnetic overlayers of Fe and Co have been investigated with X-ray Magnetic Circular Dichroism in X-ray Absorption Spectroscopy (XMCD-ABS) and Photoelectron Spectroscopy (PES), including Spin- Resolved Photoelectron Spectroscopy (SRPES), at Beamline 4 at the Advanced Photon Source (APS). Particular emphasis was placed upon the interrogation of the 2p levels of the Fe.

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**Introduction**

Over the course of several years, we have pursued the investigation of magnetic overlayers with a variety of electron spectroscopies at different synchrotron radiation facilities. [1-7] Over time, it became apparent that the most demanding experiment, the double polarization photoelectron spectroscopy or “complete experiment,” could best attempted  at Beam-line 4 at the Advanced

Photon source. [8] By combining the circularly polarized x-rays from the undulator at Beam-line 4 with the spin resolving capabilities of our Spin Spectrometer [9], it would be possible to pursue the double polarization experiment upon the 2p levels of 3d magnetic materials such as Fe and Co.

**Experimental**

Our spin-resolved photoemission spectroscopic spectrometer has been previously described [9]. The photo-excited electrons are collected in a hemispherical electron energy analyzer (Physical Electronics Model 3057) with multi-channel electron detection. (Figure 1) In the Mini-Mott, spin polarized electron detector, the electrons are accelerated to ~25 kV, with four channeltrons positioned horizontally and vertically used for electron counting. For the measurements described here, the incident angle was 55 degrees off the surface normal (in the yz plane) and the photoelectrons were collected at normal emission. All magnetic SRPES measurements were made in remanance, with the absence of an applied field during the SRPES data collection. The Cu crystal was cleaned with $Ar^+$ sputtering followed by annealing to about 450 °C. All measurements were made on Beam-line 4ID-C at the Advanced Photon Source at Argonne National Laboratory [8].

**Results and Discussion**

Ultra-thin film preparation is a crucial step in these experiments. Ultra-thin films of Fe and Co were grown on Cu(100) as in previous studies [1-7]. The films exhibited a p(1x1) LEED pattern and no observable contamination as judged from X-ray Photoemission Spectroscopy (XPS) measurements, as can be seen in Figures 2 and 3. Figures 2 and 3 also provide examples of how the film growth and contamination was followed using XPS. Obviously, the Fe, Co, Cu and Oxygen core levels can all be isolated and monitored separately.

Independently of the SRPES experiment, the magnetic character of the films of Fe and Co was determined using x-ray magnetic circular dichroism in x-ray absorption spectroscopy. [1,6] As can be clearly seen in Figures 4 and 5, strong dichroic effects are observed for both the Fe and Co, before and after the SRPES measurements. (In the plots of Figures 4 and 5, we show the uncorrected photon energy. Oftentimes, monochromators can display offsets and skewing, that vary with time. Even without correction, it is clear that these are the appropriate assignments. The correct edge energies are shown in the insets, for comparison. This effect is also illustrated in Figure 2, with the PES data.)

Ultimately, the goal was the performance of the double polarization experiment upon the 2p levels. An example of our data is shown in Figure 6. There is observation of a strong polarization and a well-behaved Instrumental Asymmetry. [10] The detailed analysis of this spectrum will be presented elsewhere. [11]

Finally, we have developed a simple single electron picture that can mimic the fundamental physical effects of the double polarization experiment. [7,11] Examples of its application to a number of limiting cases are shown in Figure 7.

Here, we have utilized an idealized configuration with a strong spectroscopic effect, then used various magnetic and spin-orbit splittings to illustrate the trends to be expected for the elemental series Fe, Co, Ni and Cu. Three Fano or dichroic cases have been considered: strong positive, zero and strong negative. These dichroic effects can change as a function of photon energy, thus the need to consider the three cases. [7] For Cu, where there is no magnetism, only the spin-orbit driven effects will be observed. As expected, for the zero dichroism case, the Cu spin up and spin down spectra are identical and the ratio is identically one. For the strong dichroism cases (c = +/- 0.5), the retention of the dichroism can be seen as the exchange splitting grows progressively from Ni to Co to Fe. Interestingly, our experimental result for Fe looks like the zero dichroism case and this is not unexpected. In that experiment, the strong magnetic moment and the experimental geometry converge to miminize the impact of the circularly polarized x-rays. The detailed discussion of this result is presented elsewhere. [11]

**Summary**

We have successfully carried out double polarization photoelectron spectroscopy of Fe/Cu(001) at Beam-line 4 of the Advanced Photon Source. Supporting measurements as well as the results of a single electron model were presented and briefly discussed.

**Acknowledgments**

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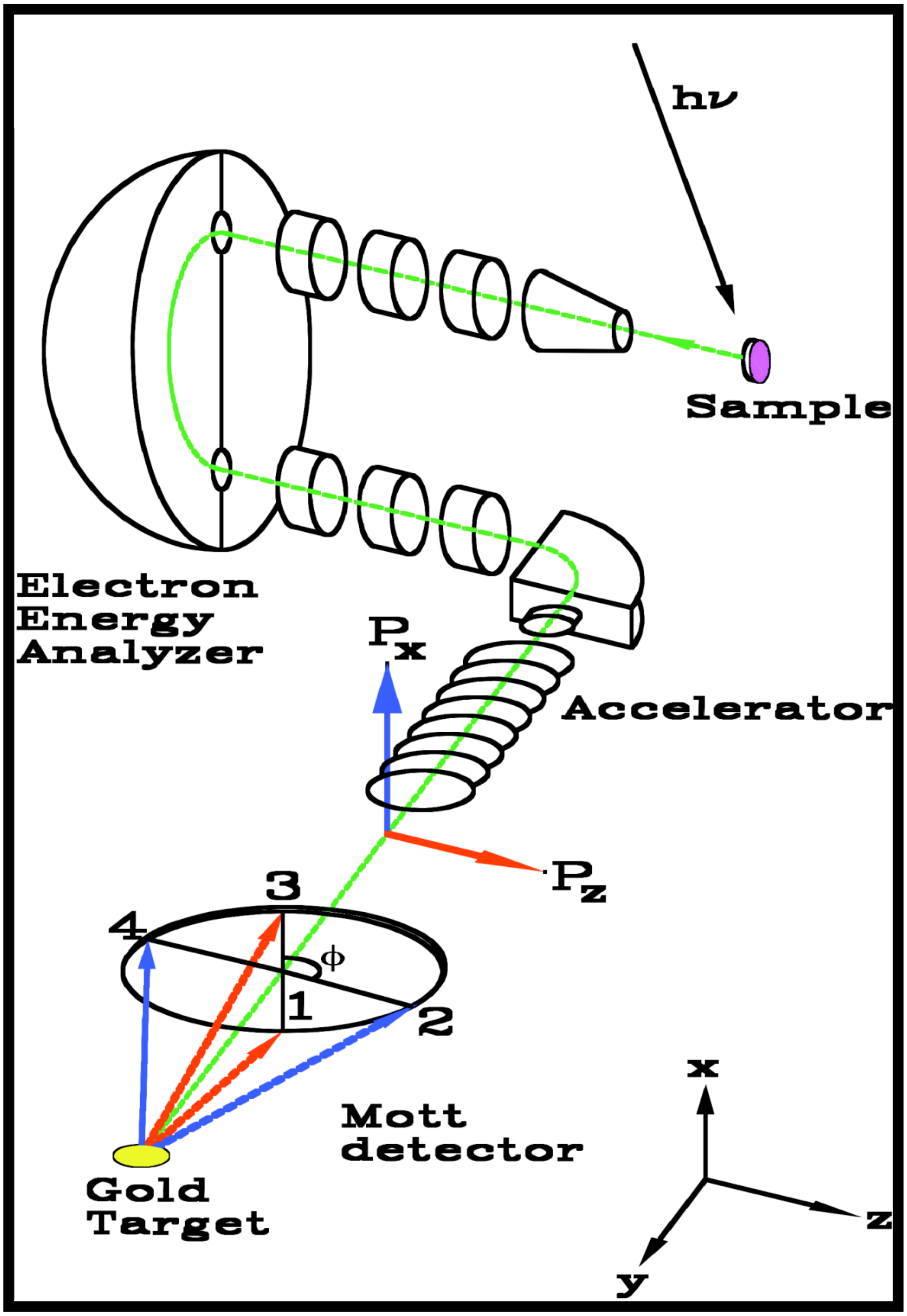


Figure 1
Experimental layout. See text for details.

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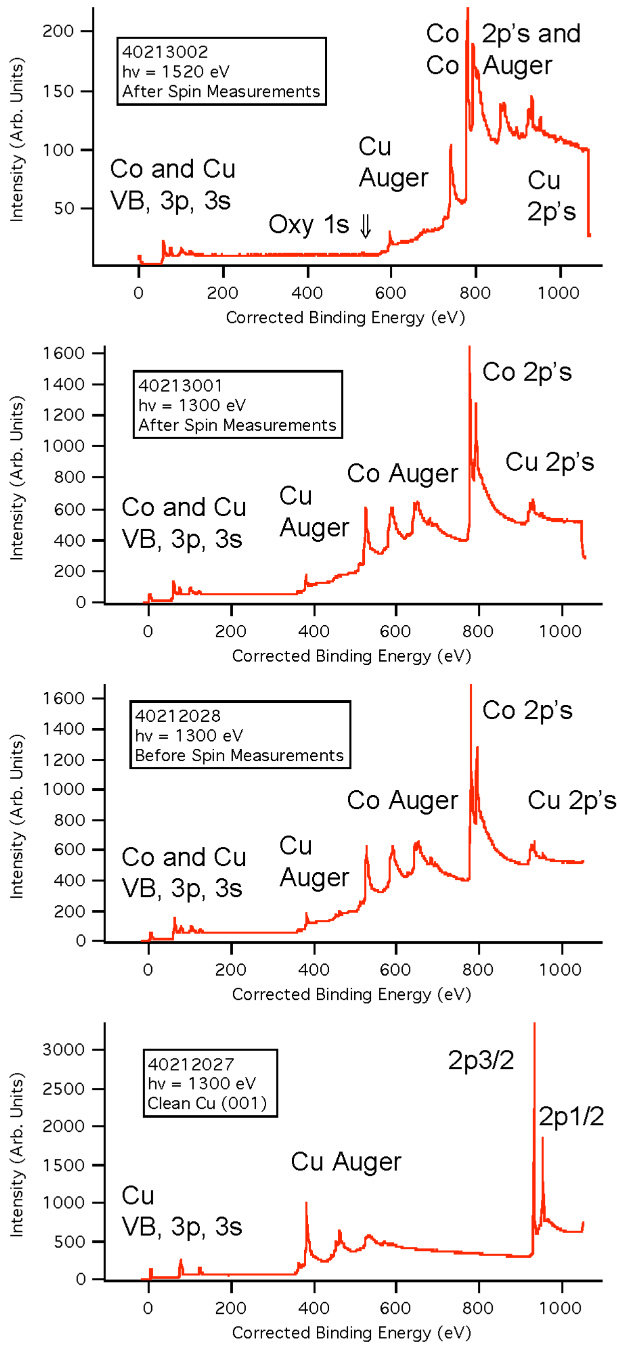


Co Spin Exp-Wide Scans
27Feb08

Data from Feb 2004

Nominal Photon Energies
1250eV (MgKa) and
1450eV (AlKa)

Corrected Photon Energies
Approximately 1300 eV
And 1520 eV

Nominal Coverage
10 ML Co/ Cu(001)

Plot widths are from
-100 to 1100 eV BE.

Figure 2
Wide PES or X-ray Photoelectron Spectroscopy (XPS) scans of Co/Cu(001) using hv = 1300 and 1520 eV.

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Fe Spin Exp-Wide Scans 29Feb08
Data from Feb 2005

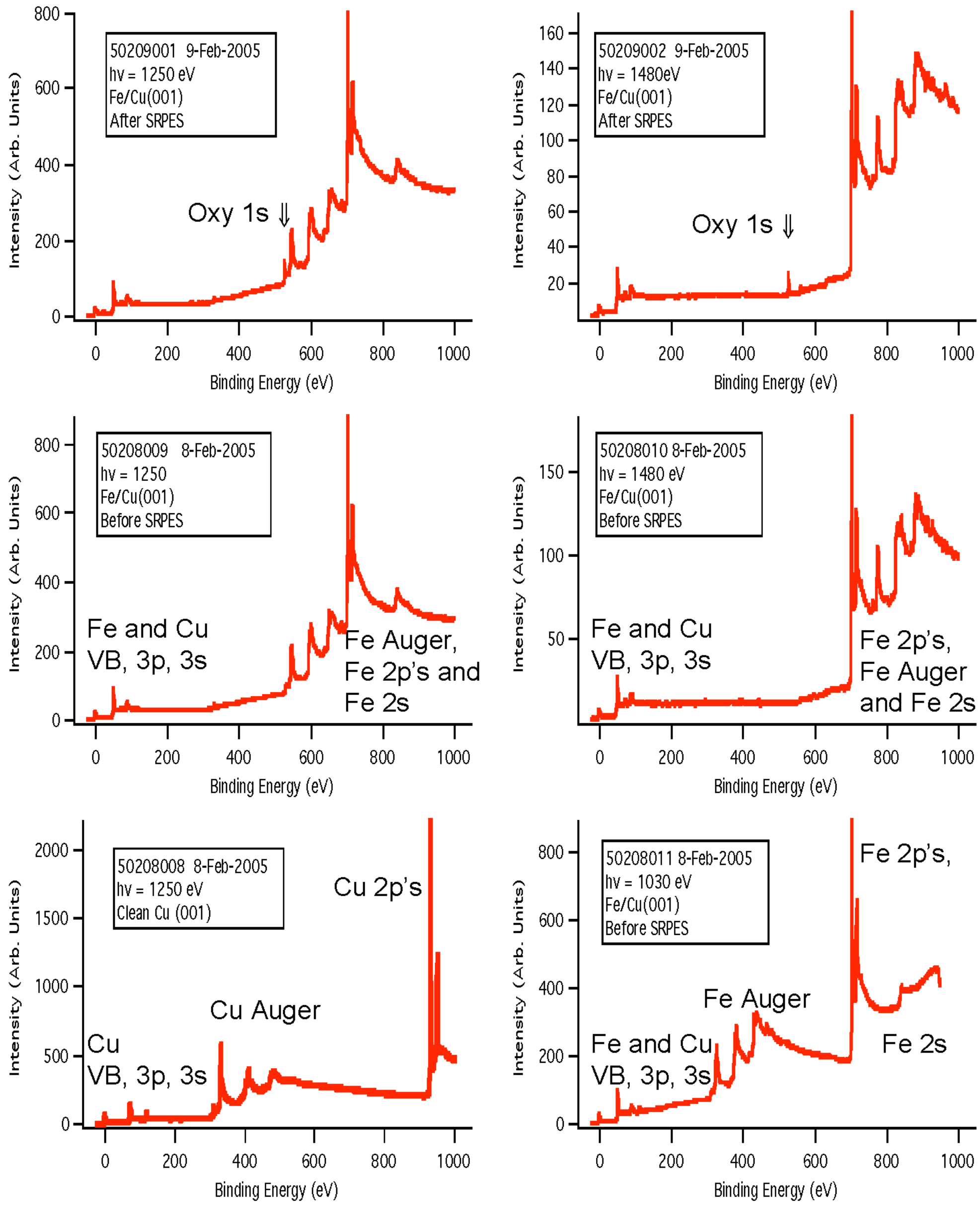


Figure 3
Wide PES or XPS scans of Fe/Cu(001) using hv = 1250 and 1480 eV.

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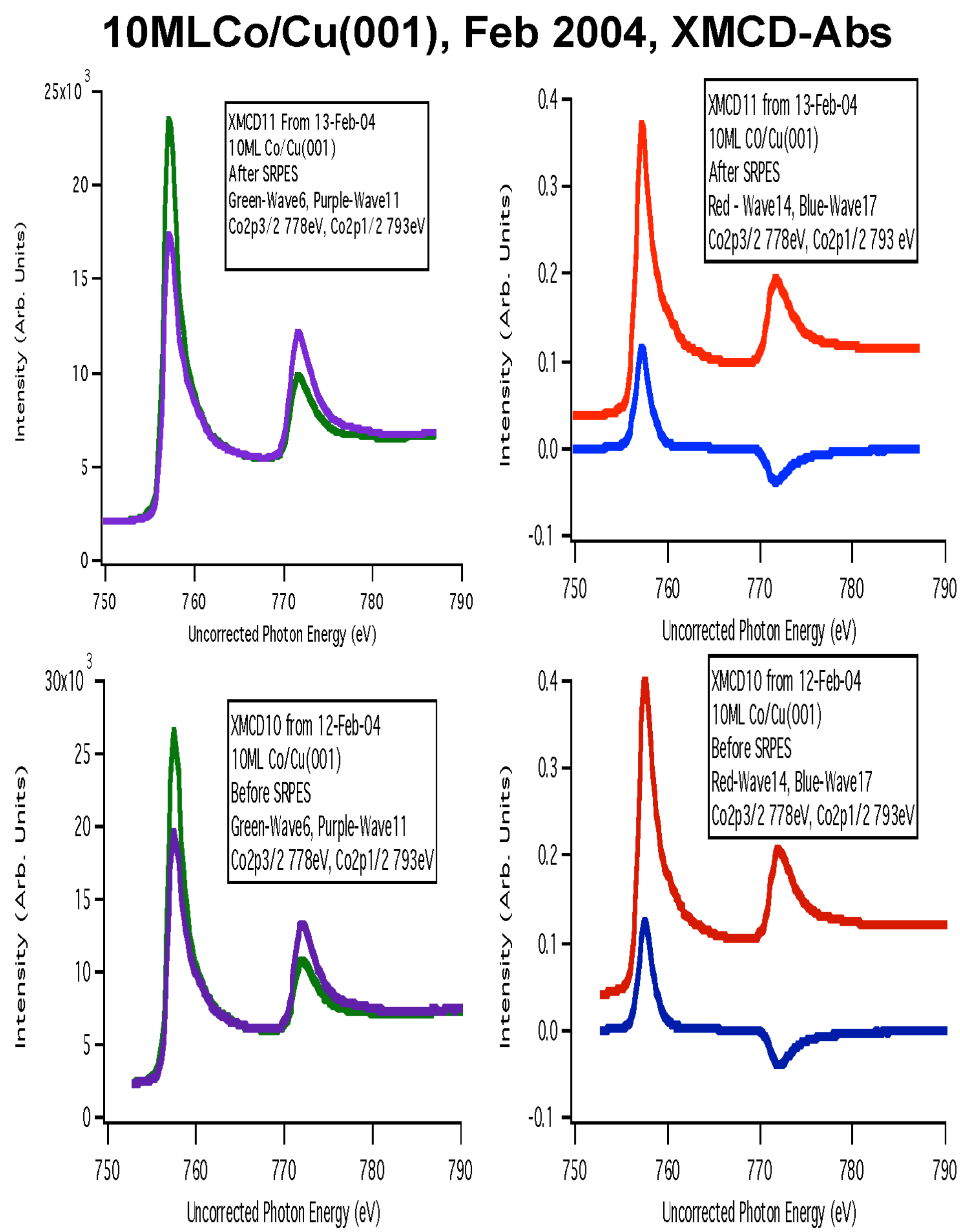


Figure 4
XMCD-Abs of Co/Cu(001). The plots in the left column show the “raw” spectra, with magnetization reversal or helicity reversal. The right column includes plots of the corresponding sums (red) or differences (blue). The Bottom and Top correspond to before and after the various SRPES measurements, respectively.

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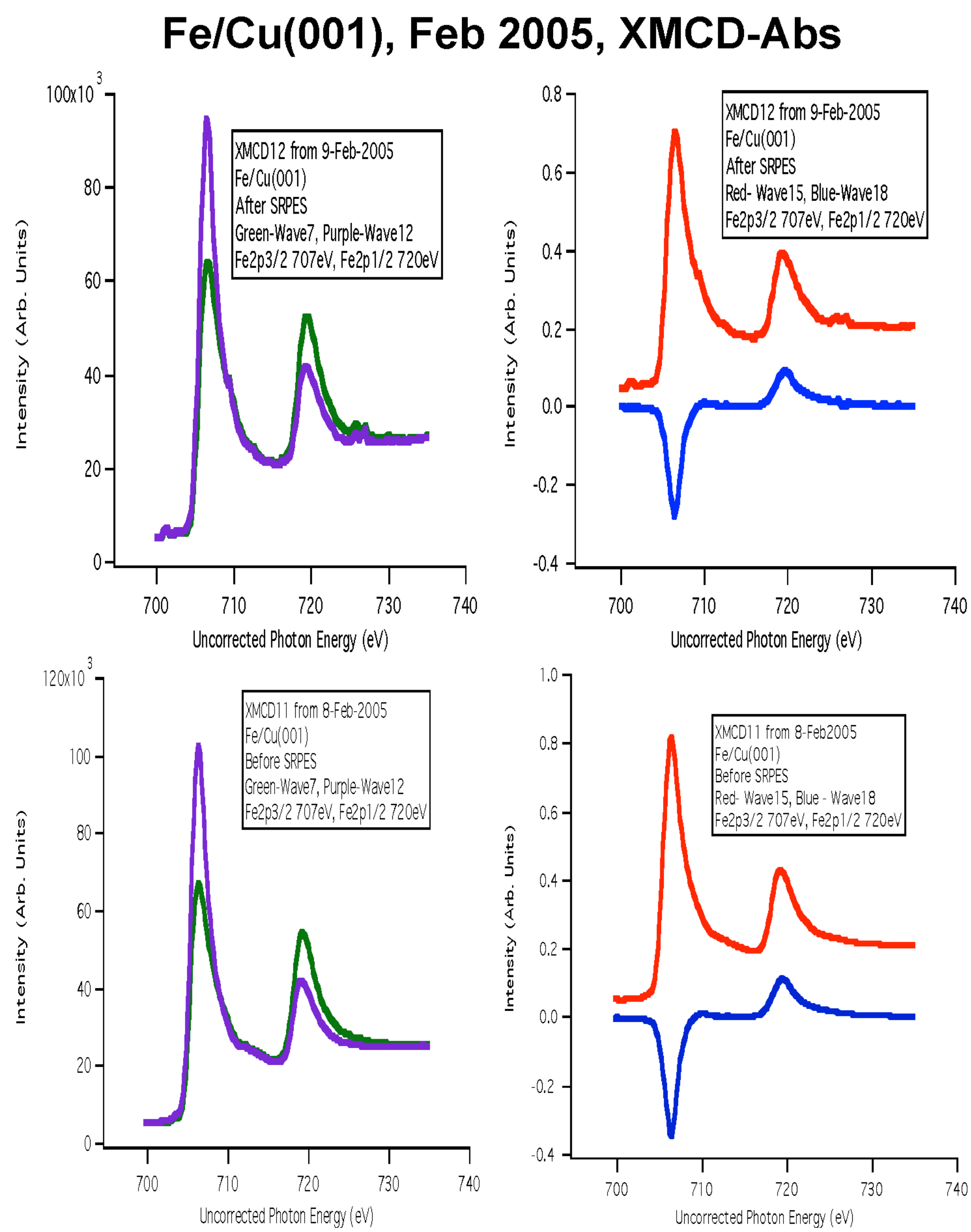


Figure 5
XMCD-Abs of Fe/Cu(001). The plots in the left column show the “raw” spectra, with magnetization reversal or helicity reversal. The right column includes plots of the corresponding sums (red) or differences (blue). The Bottom and Top correspond to before and after the various SRPES measurements, respectively.

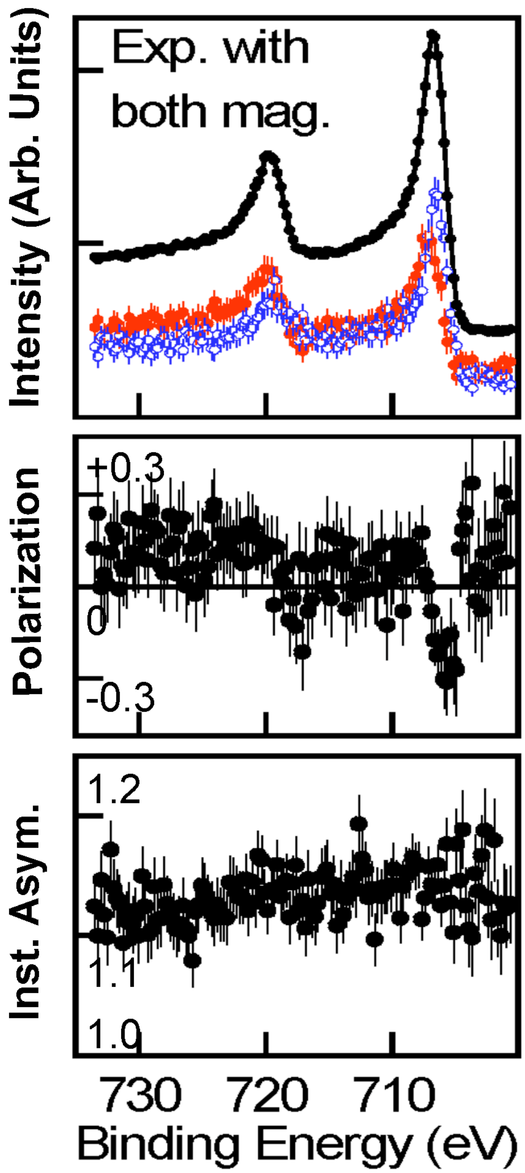


Figure 6

Spin resolved photoelectron spectroscopy (SRPES) of macroscopically magnetized Fe films. From the top, the following are shown: Experimental spectra, polarization and instrumental asymmetry. [7,10] Here, the axis of quantization is along the +/- x direction, following the magnetization. The photon energy was 1030 eV, with right circular polarization.

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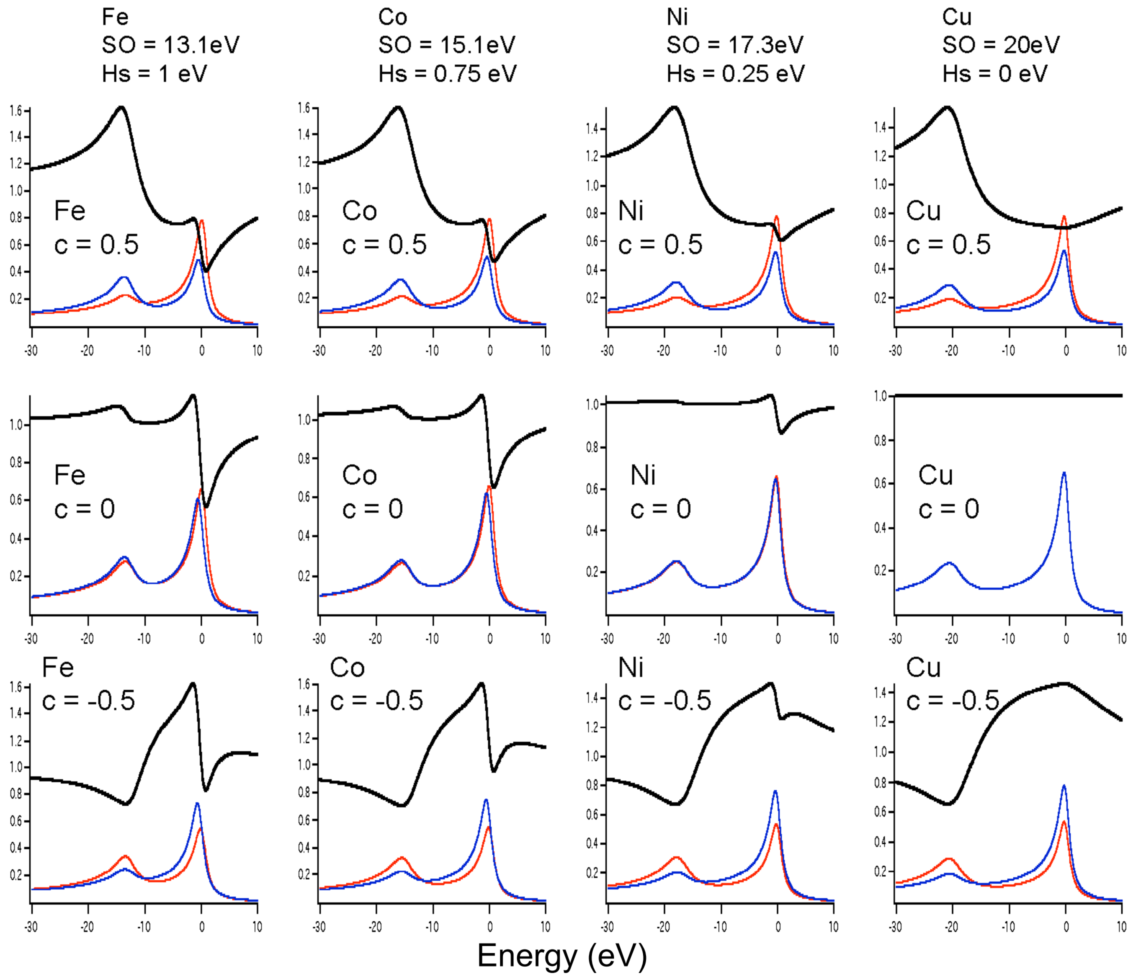


Figure 7
The simulated spectra for an idealized configuration and a number of limiting cases, using our single electron model. [7,11] Spin up is red. Spin down is blue. The ratio of the spin down to spin up is shown as a black line. To avoid divergence, the ratio was calculated as ratio = [I (spin down) + small constant] / [I (spin up) + small constant]. Three dichroism cases were considered: c = 0.5 (strong positive); c = 0 (no dichroism); c = -0.5 (strong negative dichroism). Four spin orbit cases were utilized, corresponding to Fe, Co, Ni and Cu. SO is the effective spin orbit splitting of the 2p3/2 and 2p1/2 levels. [12] Hs is the exchange splitting, obtained in part from scaling from the magnetic moments of each element. [5,7]